# Polar Warming Revealed by Cryosphere Changes


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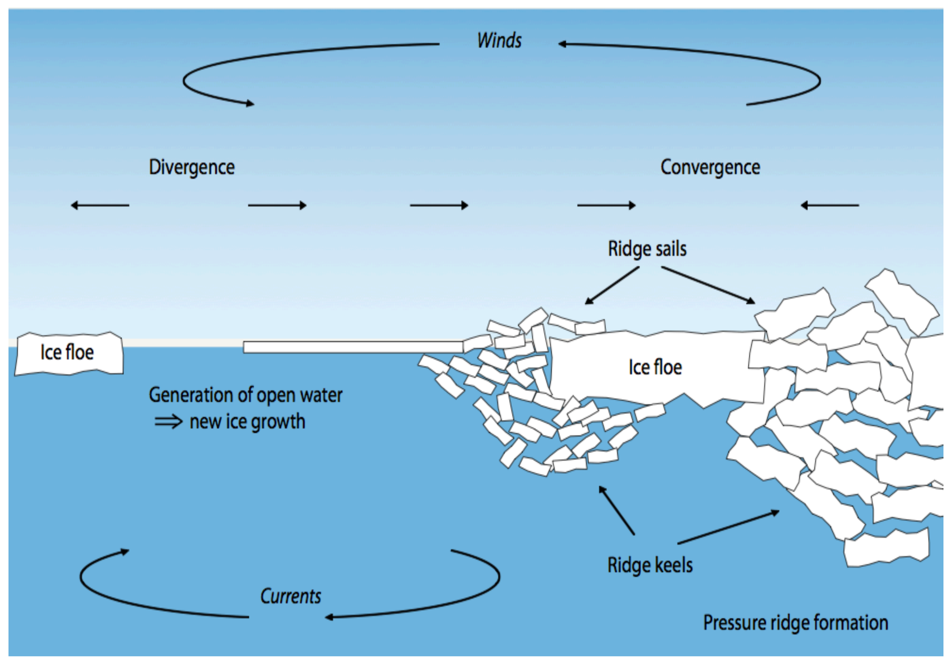
## Introduction & Background

The Advanced Very High Resolution Radiometer (AVHRR) Polar Pathfinder - Extended (APP-x) satellite product covers a 35-year period starting from 1982. APP-x has twice-daily fields of surface (temperature, albedo, ice thickness), cloud (fraction, phase, optical depth, particle size, and thickness), and radiation properties for both poles. APP-x shows new record lows in Arctic sea ice concentration, extent, thickness, and volume in Fall 2016, as well as dramatic declines in Antarctic sea ice in recent years, which reached a record low in Fall 2016. Other products have shown strong responses in snow, permafrost, glaciers, and ice sheets to the warming trend as well.

The Arctic autumn sea ice extent in 1982 was $1.096{*}10^7$ km$^2$, but has since declined to $6.9306{*}10^6$ km$^2$ at an annual rate of $-1.3169{*}10^5$ km$^2$. The Arctic autumn sea ice concentration, thickness, and volume have all decreased at annual rates of 0.30%, 0.36 cm, and 169 km$^3$, respectively. For the Antarctic, the rapid decline in sea ice started in 2013. In Fall 2013, ice extent of $1.6261{*}10^7$ km$^2$ declined to $1.4708{*}10^7$ km$^2$ in Fall 2016 at a rate of about $-5.1766{*}10^5$ km$^2$ per year. This short-term rate of change was more than one order of magnitude larger than the rate of $-1.3691{*}10^4$ km$^2$ per year for the period 1982-2016 in the Antarctic, and 3.9 times larger than the rate of change in the Arctic since 1982.

## APP-x Ice Thickness




Processes that affect ice thickness. *(from SWIPA, 2011)*

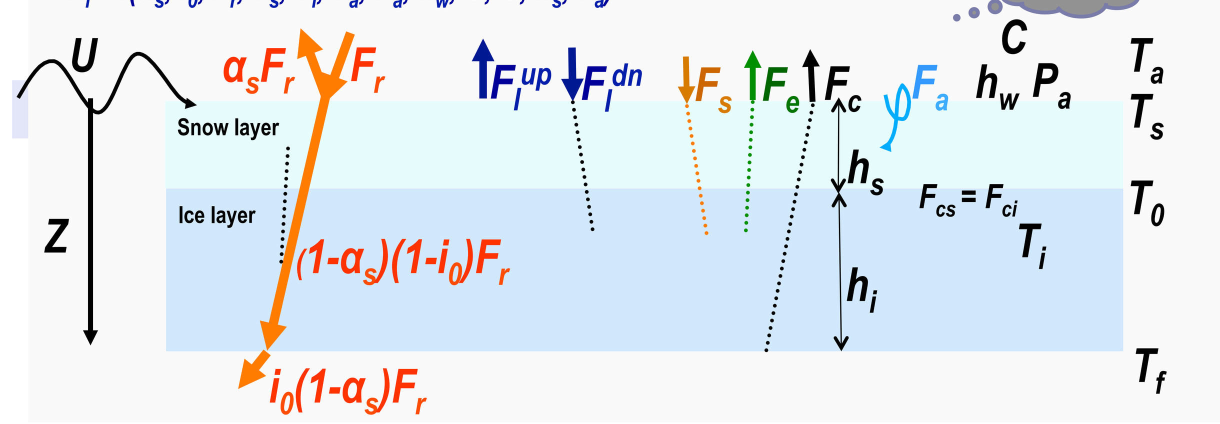
**One-dimensional Thermodynamic Ice Model (OTIM)**

Based on the surface energy budget at thermo-equilibrium state, the fundamental equation is

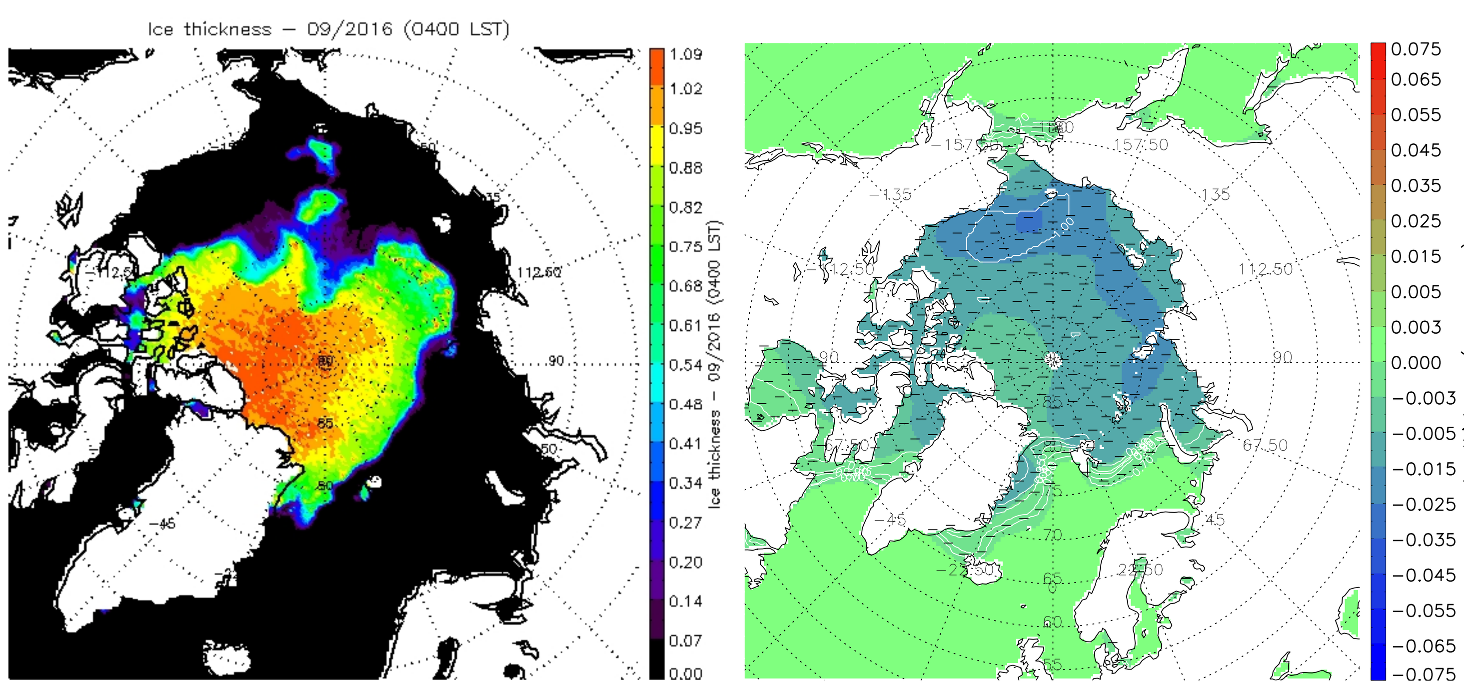
$$(1-\alpha_s)(1-i_0)F_r - F_l^{up} + F_l^{dn} + F_s + F_e + F_c = F_a(\alpha_s, T_s, U, h_i, C, h_s, \ldots)$$

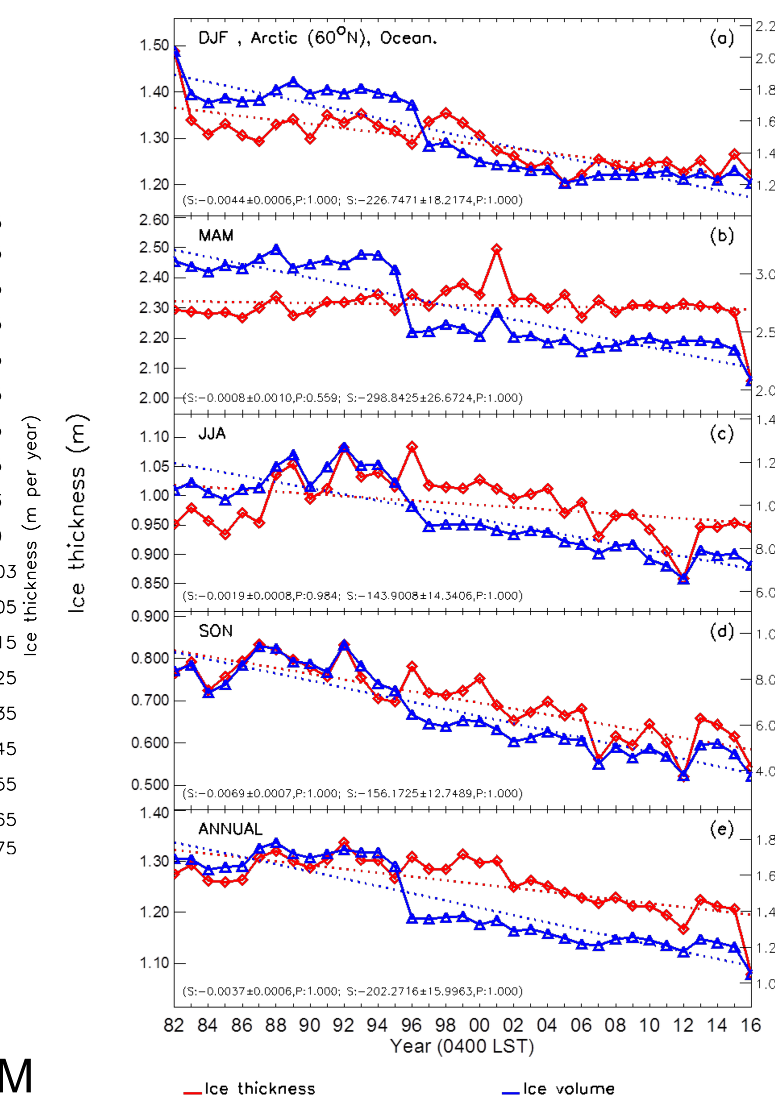
After parameterizations of thermal radiation ($F_l^{up}$, $F_l^{dn}$) and turbulent (sensible & latent) heat ($F_s$, $F_e$), ice thickness $h_i$ becomes a function of 11 model controlling variables:

$$h_i = f(\alpha_s, i_0, F_r, T_s, T_i, T_a, P_a, h_w, U, C, h_s, F_a)$$

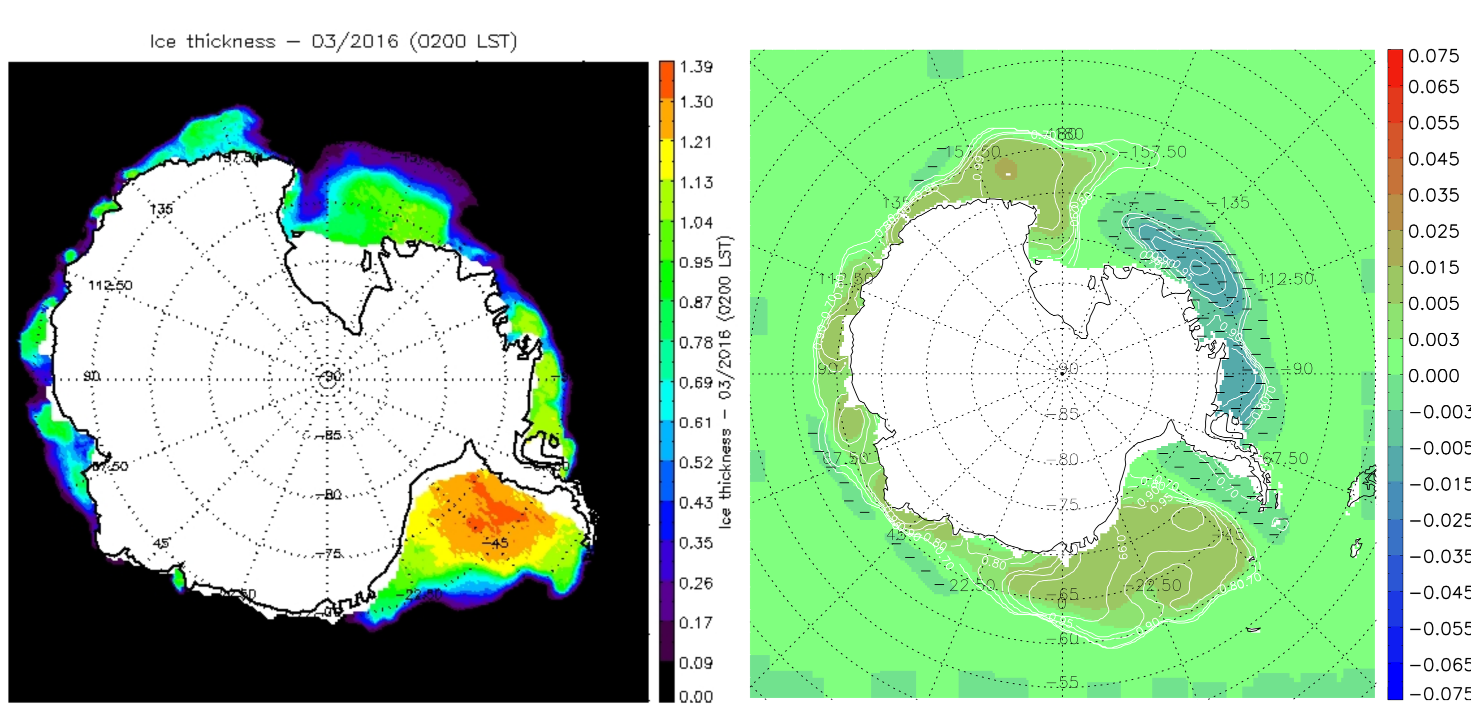


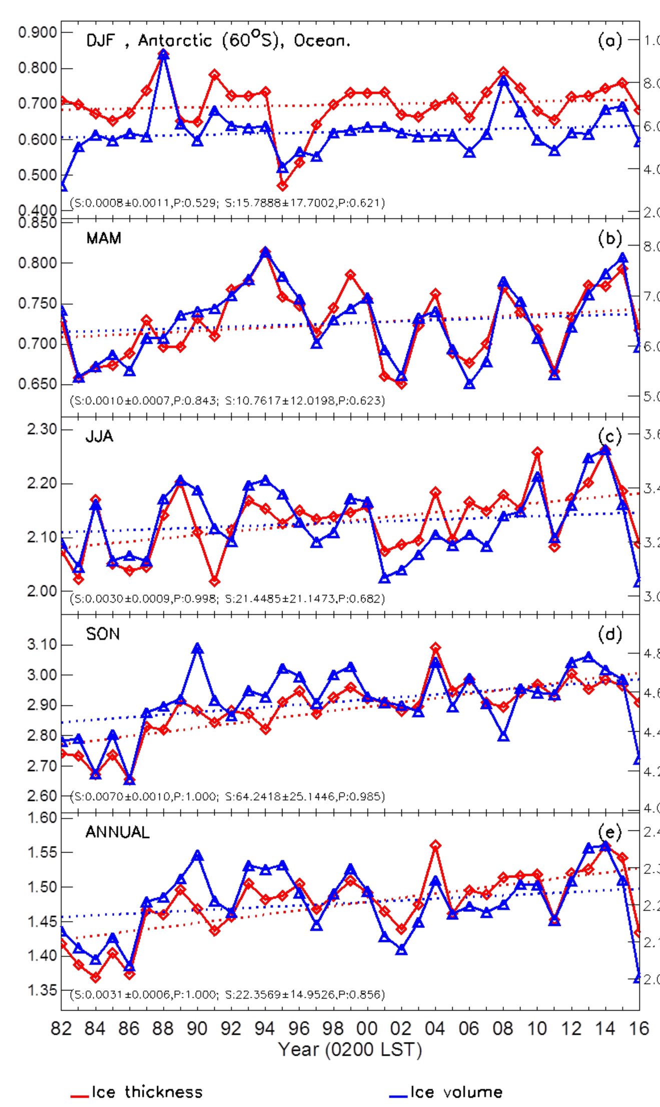

The OTIM schematic illustration of physical processes considered in ice thickness estimation.



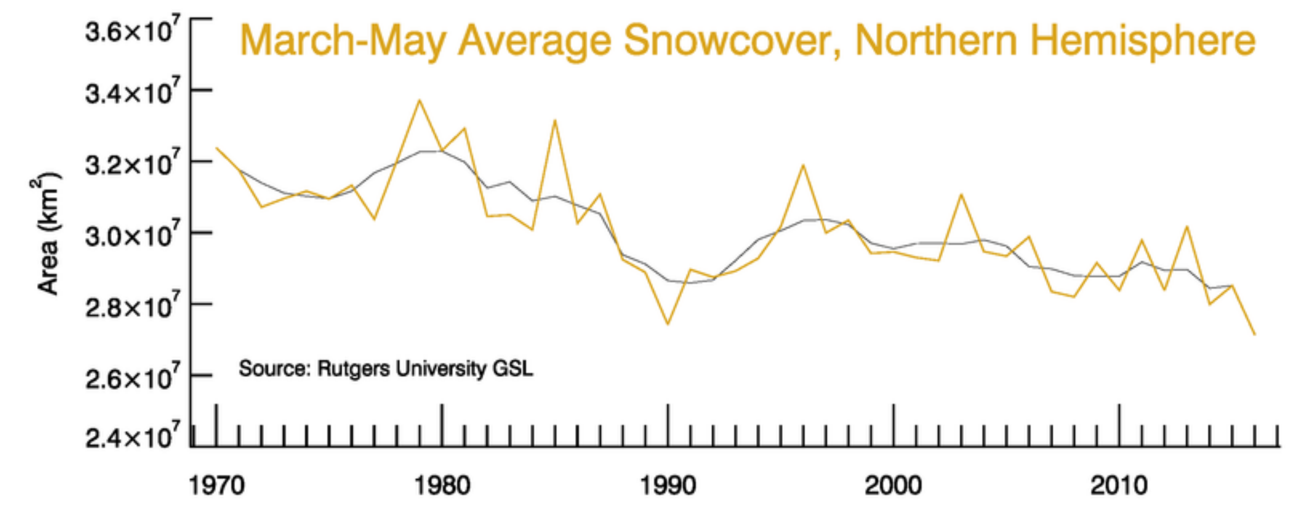



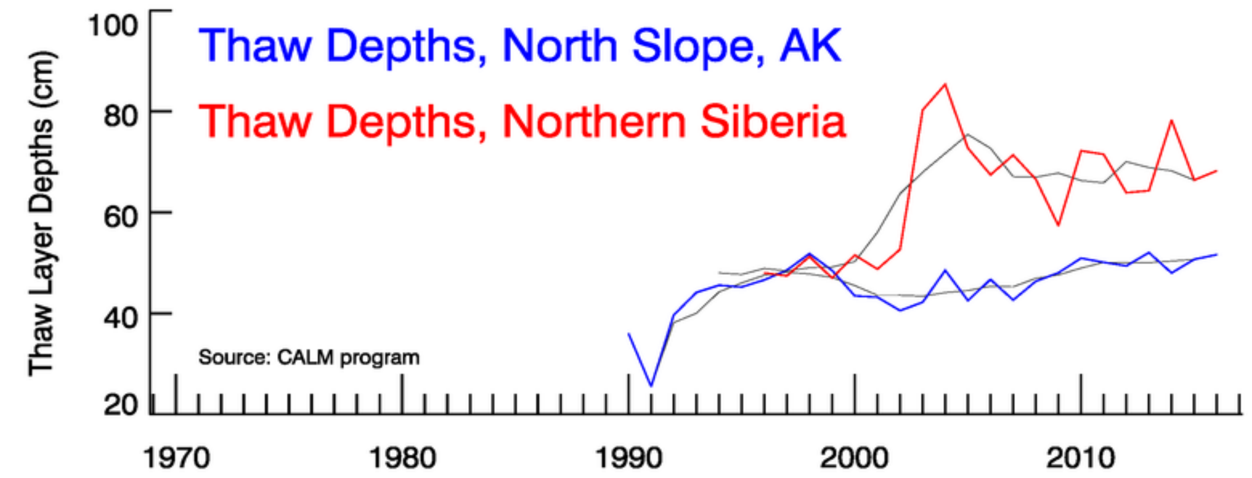

Left: Arctic sea ice thickness from OTIM in September 2016. Center: Arctic sea ice thickness trends from OTIM in Autumn (Sept. – Nov.) over 1982-2016. Right: Arctic sea ice thickness and volume from OTIM over 1982-2016.

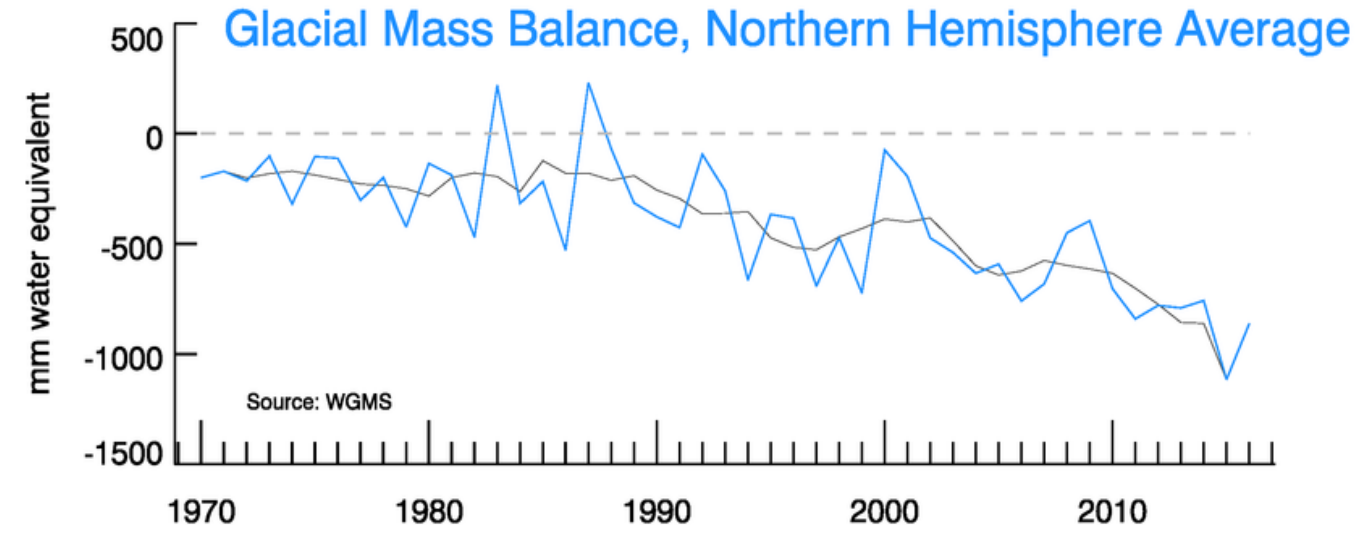


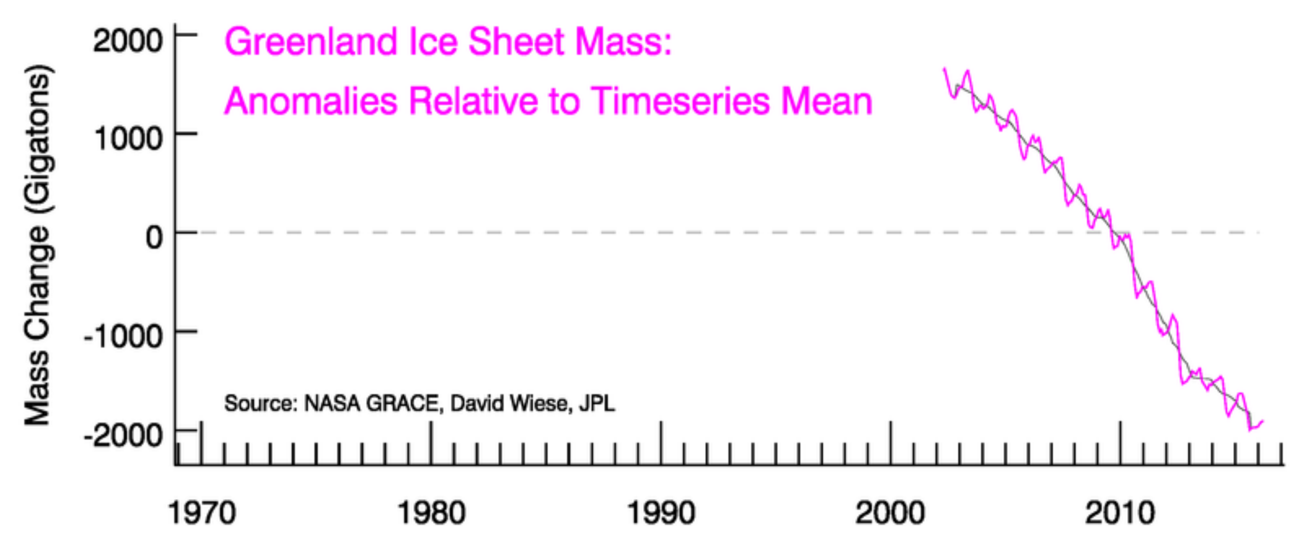



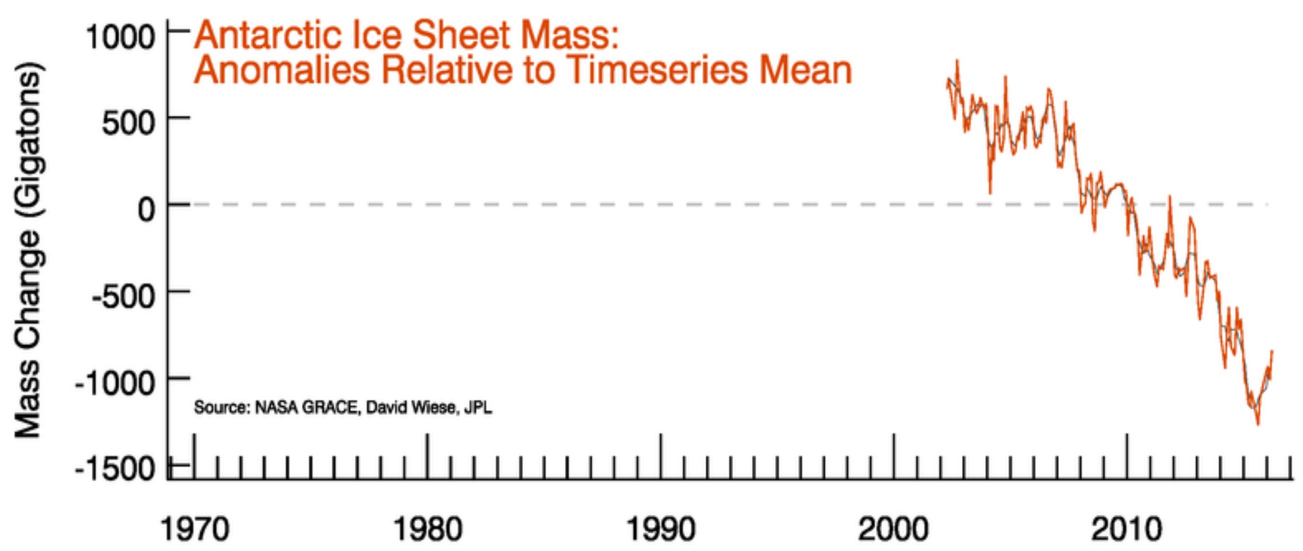

Left: Antarctic sea ice thickness from OTIM in March 2016. Center: Antarctic sea ice thickness trends from OTIM in Autumn (March - May) over 1982-2016. Right: Antarctic sea ice thickness and volume from OTIM over 1982-2016.




**Left (from top to bottom)**:

Spring Snow Cover from Rutgers University Global Snow Lab.

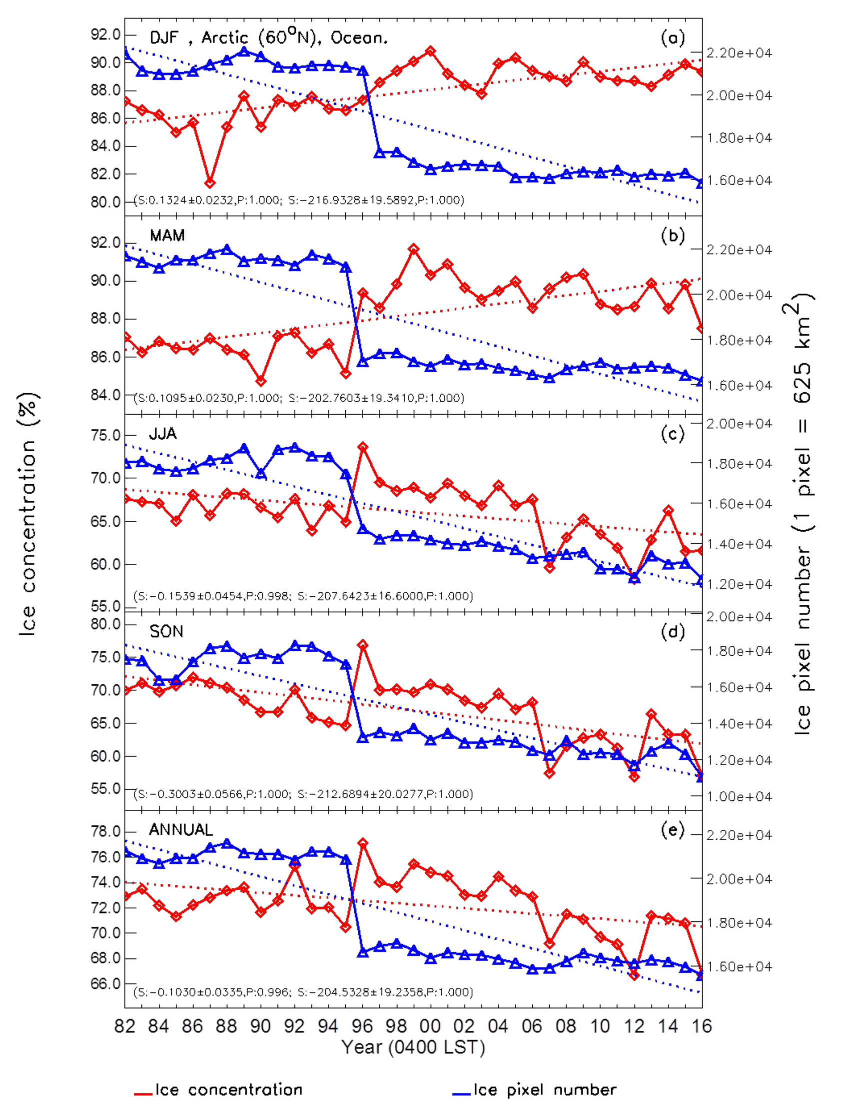
Permafrost Thaw Depths from the Circumpolar Active Layer Monitoring program, Alaskan and Siberian sites.

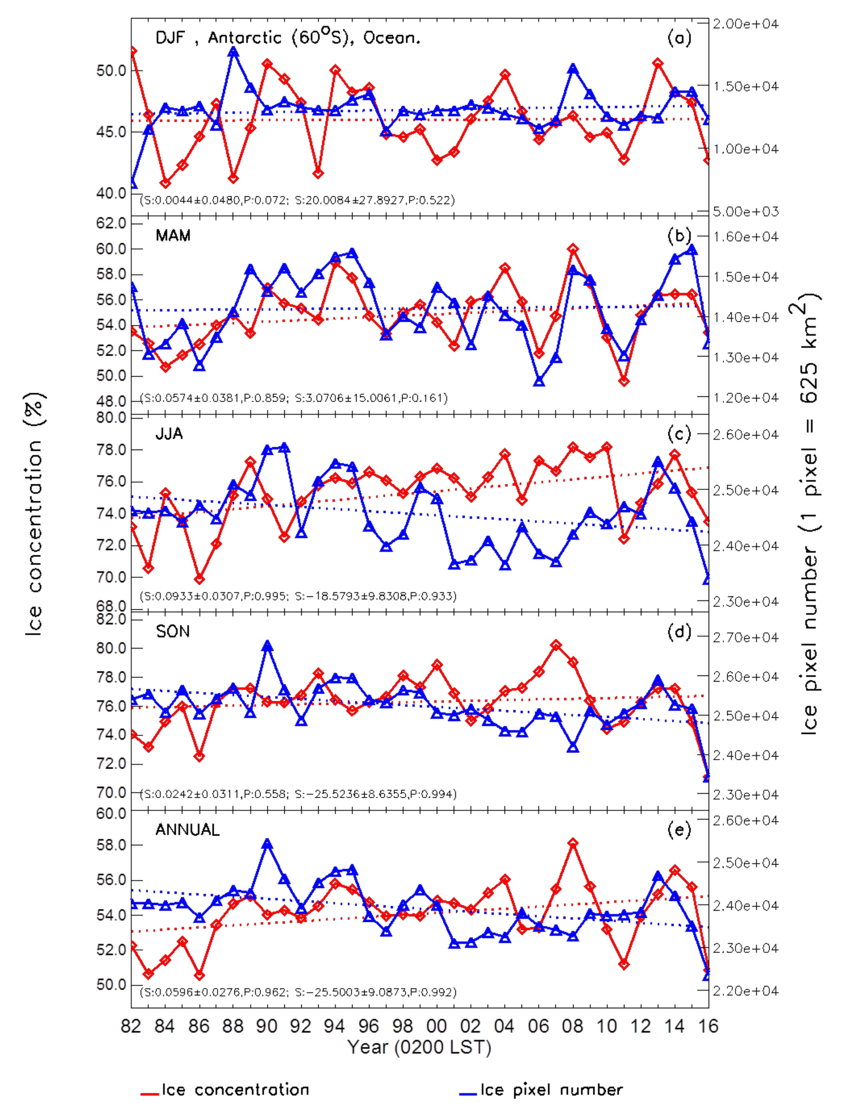
Glacial Mass Balance (Northern Hemisphere) from the World Glacier Monitoring Service.

Greenland Ice Sheet Mass Anomaly (top) and Antarctic Ice Sheet Mass (bottom), from NASA Gravity Recovery and Climate Experiment (GRACE) provided by David Wiese, Jet Propulsion Laboratory.


**Below left:** Arctic sea ice concentration and area from OTIM over 1982-2016.

**Below Right:** Arctic sea ice concentration and area from OTIM over 1982-2016.





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